SOME GENERAL THOUGHTS ON TWO BODY SMALL MOMENTUM TRANSFER SPECTROMETER EXPERIMENTS AT HIGH ENERGIES

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I want to consider a general class of reactions of the type $A + p \rightarrow C + D$ where A could be any incoming particle and C and D are either particles or resonance states with C being the forward going particle. In the energy range from 50 - 100 GeV/c the cross section for any individual channel should be of the order of a few microbarns. Extrapolation from lower energy indicates that the reactions will be peaked forward so that a large fraction of the cross section will be in a region $-t < 1\ (\mathrm{GeV/c})^2$. One can envision two types of experiments which will be of theoretical interest. One is the measurement of angular distributions (and polarization in some cases) as a function of energy for individual channels. Another would be to measure C summing over all or a certain class of states of particle D. I will not consider elastic scattering explicitly although spectrometer parameters will be pertinent to elastic scattering as well as inelastic processes.

It is quite feasible to separate incoming π, K, and p using Č counters (see M. Longo, Vol. 1, p. 164, Berkeley Study). Counters 100 - 200 feet long are required. Construction looks relatively straightforward. I will not discuss the problem further here.

The fast forward going particle is produced at a lab angle of $\sim 1^\circ$ at 50 GeV/c and $.5^\circ$ at 100 GeV/c for $-t = 1.0$. Let us assume for the present that it is useful to have a magnet to momentum analyze these forward particles (which may or may not be useful or feasible). What characteristics should such a magnet have? For purposes of spectrometer magnet calculations the forward particle will have essentially the same momentum as the incoming particle. (The decay particles from forward produced resonances are usually slower. Worry about these later.) A bending angle of about 0.10 radians with reasonable length lever arms ($\sim$5 meters) for measurement of angle will give 0.1% accuracy in momentum. This seems to be a good number to shoot for. While it will not separate reactions where heavy mesons are produced, it is accurate enough to resolve nucleon resonance production. For 100 GeV particles a magnet with $\int B d\ell = 1.3 \times 10^4$ kg.-in is required.

A great deal more thought should be given to obtaining field uniformity in the magnet than has been done on similar magnets in the past. While any trajectory can be integrated through the wildest field there is a great saving in computer time, an ease of designing experiments, and a gain in real-time on line computer operation which leads to an enormous advantage if the field is reasonably uniform (< 1%). These factors are so important that if a very high field magnet cannot be designed with sufficient uniformity a considerable reduction of field should be considered to achieve such uniformity.

It is probable that the magnet should be designed in two or three sections to allow for flexible use where smaller momenta and larger angles are involved.

At 100 GeV, in order to measure differential cross sections to .01 $(GeV/c)^2$ in t, an accuracy of .001 radian is needed in the scattering angle. Kinematics indicates that a mistake in angle of .001 radian transforms into 0.1% in momentum. The angle measurement needed for .1% accuracy in momentum is a factor of 10 smaller.

In general, momentum analysis of the sideways going nucleon is far easier and less expensive. The sideways particle has approximately the same momentum for a given t value independent of incoming momentum and therefore analysis of its momentum remains relatively easy. In experiments where the momentum of the final baryon going sideways is measurable it will supply the best measurement of momentum transfer. The problem with the slow particle is not as easily defined as that of the fast particle. The slow particle can go anywhere in the forward hemisphere depending on the reaction and t value being studied. Momenta similarly vary from near 0 to a couple of GeV.

If the slow particle is a proton then for zero momentum transfers it will go forward. As the momentum transfer rises its angle increases rapidly. For $-t > .1$ the angle is almost independent of momentum transfer and depends on the mass of the meson resonance produced. To get information about the mass of the meson resonance one needs very good angular measurements (.001 rad) but only crude momentum measurement. On the other hand, the momentum transfer $-t = 2m_p T_p$ (T_p - proton kinetic energy) is independent of meson mass. In general, if the proton has enough energy to leave the target its angle will be $> 70°$ at 50 GeV except for very massive meson resonances. In the t range of interest its momentum will be < 1 or 2 GeV. For $-t < .1$, it will usually not make it out of the target.

For these slow particles momentum measurements to a few percent should be adequate for most experiments, but angle measurements might be desired to .001 radian. A 1 meter path to make the angle measurement followed by a small magnet with $\int Bdl < 500$ kg in. is appropriate.

What general things can we say about the kinematics of small momentum transfer reactions?

1) Reaction in which nucleon recoils with no change in mass. Meson changes mass (diffraction dissociation of meson, ρ production) $m_d = m_p \quad m_a \neq m_c$.

Then for 0° production

$$\Delta p_1 \equiv (p_a - p_c)_{0^\circ} \cong \frac{m_c^2 - m_a^2}{2p_a} .$$

Even with .1% momentum accuracy Δp_1 is unmeasurably small unless m_c is above 4 GeV or so. The same applies to non-zero angles. The class of processes where you would want to measure mass directly are essentially nonexistent anyway because all the resonances decay and one must deal with the decay products.

2) Reaction in which nucleon is excited, meson remains unchanged (diffraction dissociation of nucleon, fireball production, resonance production) $m_d \neq m_p \quad m_a = m_c$

$$\Delta p_2 \equiv (p_a - p_c)_{0^\circ} = \frac{m_d^2 - m_p^2}{2m_p}.$$

Here the situation is considerably better. N^*1236 production at 50 GeV has $\frac{\Delta p_2}{p_a} \sim .6\%$.

3) Both masses change (strange particle production, diffraction dissociation of both particles)

$$\Delta p_3 \equiv (p_a - p_c)_{0^\circ} \sim \Delta p_1 + \Delta p_2 \sim \Delta p_2 \text{ at high energy.}$$

Thus Δp_3 at 50 GeV is dominated by change in mass of baryon. You can measure mass of baryon but not meson (see 2).

Measurement of excited nucleon states:

$$\left.\begin{matrix} p \\ \pi \\ K \end{matrix}\right\} + p \begin{matrix} \rightarrow \\ \rightarrow \end{matrix} \left.\begin{matrix} p \\ \pi \\ K \end{matrix}\right\} + N^*$$

This involves an accurate momentum measurement of incoming and outgoing π to $\sim.1\%$, measurements at a variety of angles from 0 to 10 or 20 mrad and measurements as a function of energy. The cross section for this reaction integrating over N^* states might be as high as a few hundred microbarns. From the angular distribution one could deduce whether diffraction dissociation of the nucleon or some other mechanism was responsible for the various resonances.

The reaction points up one of the difficulties which will be encountered at these very high energies. It is in many cases going to be interesting to measure 4 momentum transfers that are $\sim.01$ $(\text{GeV})^2$ or less. These require measurement of angles of the forward particle to 1 mrad or measurements on the recoil particle.

Interpretation of the data might become confusing if the outgoing forward particle lost a large fraction of its momentum in the collision. Say it lost 10% of its energy at 100 GeV. Then $\Delta p_2 = 10$ GeV $\quad m_d{}^2 - m_p{}^2 = 2 \times .94 \times 10 = 18.80.$ Thus mechanisms for production of excited nucleons or "fireballs" to 4 GeV or so could be investigated by this method.

Study of ρ production:

This is an interesting reaction theoretically since it is expected that ω exchange should be dominant at high energy in contrast to π exchange which seems to dominate at low energies. Three characteristics which would indicate the type of mechanism are the production angular distribution, decay angular distribution, and the behavior of the cross section with energy.

Probably the easiest state to measure is the ρ^0 since one can calculate the mass from the opening angle and momentum. To separate production via $\pi^- + p \rightarrow \rho^0 + n$ from that in which an N^* is produced along with a ρ requires very good momentum measurement on the ρ (see Δp_2 page 5). Therefore the sum of the momenta of the two π's from the ρ decay should be measured to $\sim .1\%$. To design such a spectrometer system for 50 GeV, consider the following parameters:

1) $\theta_{prod.}$ for $-t = 1\ (\mathrm{GeV})^2$ is $\sim 1.2°$ or .021 rad. Let's assume we want to measure out to $-t = 1\ (\mathrm{GeV})^2$.

2) The maximum opening angle for the decay is 2.5°. The decay opening angle in the symmetric case is 0.8°.

3) The decay π's range in momentum from 51 to 1 GeV/c.

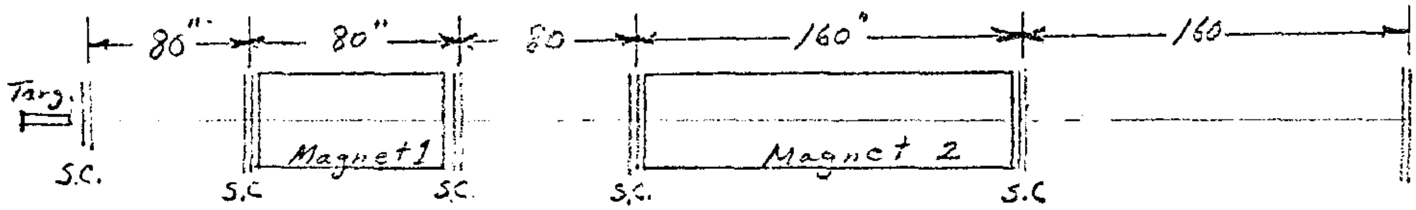
4) The small momentum π's have the large angles relative to the ρ production.

Because of the large momentum spread it seems wise to design the spectrometer in two or more sections so that the gap width and height can be kept to a minimum for the high energy particles where a large $\int Bdl$ is needed.

A reasonable choice would be

1st Magnet	Width 1m	Height 12"	Length 72"	Field 30 kg.
2nd Magnet	Width 1m	Height 16"	Length 144"	Field 30 kg.

with the geometry shown in the drawing.



Such a system would give 1 event/10 pulses per μb for 10^6 incoming π's.